GLOBAL BROADCAST SERVICE PAYLOAD - UTILIZATION OF COMMERCIAL TECHNOLOGIES FOR MILITARY APPLICATIONS

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ABSTRACT

In April 1995, the government validated the Mission Need Statement for the Global Broadcast Service (GBS): to provide high bandwidth one-way communications to tactical forces in garrison, in transit, and deployed. GBS will enhance current MILSATCOM capabilities by providing multi-megabit per second data delivery (up to 120 megabits per second per spacecraft) of intelligence, imagery, map, and video data to users with small, portable, and affordable terminals.

Commercially available technology has been applied to provide on-orbit delivery of the Phase II GBS Payload integrated on the Navy's UHF Follow-on Program satellite on an aggressive 24 month schedule under a fixed price contract. The development and implementation this payload, under the leadership of the Hughes-Navy team, is an outstanding example of the benefits to be derived from the application of commercial technologies to military applications under the new government acquisition reform policies.

BACKGROUND

Information Warfare has become a primary element of the modern battlefield. Many information products in today's military environment contain large data files, which require significant transmission time and can consume multiple low speed channels on existing Military Satellite Communications (MILSATCOM) resources, such as Milstar, DSCS, and UHF Follow-On (UFO). The ability to disseminate, analyze and exploit vast amounts of data provides the modern warfare commander a new "high ground". Winning the information war depends on DoD's ability to provide simultaneously critical information to all approved recipients in the theater. Existing military communications were not designed to provide high capacity broadcast services to multiple receivers, both fixed and mobile, using small receive terminals. The existing communications paths are over-subscribed and in most cases provide too narrow a "pipe".

Traffic analysis shows a predominate amount of traffic flows one way: out to the user. This means that two-way capabilities are being used for one-way traffic. Many users require the same information, but existing paradigms require the information to be sent individually to each user which only exacerbates traffic congestion.

Information types and message size also contribute to the existing architecture's inability to rapidly disseminate data. Table 1 provides typical examples of message types, size and dissemination time over representative communications paths.

Example Information	Existing DoD SATCOM Systems Throughput			
SATCOM Throughput	2.4 Kbps (e.g. Milstar & UFO)	512 Kbps (e.g. DSCS)	1.544 Mpbs (e.g. MDR Milstar)	24 Mbps (e.g. GBS)
Air Tasking Order (8.8 Mbits)	1.02 hr	17.2 sec	5.7 sec	0.37 sec
Tomahawk Mission Update (02.4 Mbits)	100 sec	0.47 sec	0.16 sec	0.01 sec
Imagery (193 Mbits)	22.3 hr	6.28 min	2.08 min	8.04 sec
Logistic Message (2000 Mbits)	9.65 days	1.09 hr	21.59 min	1.39 min

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Table 1. Typical DoD SATCOM Data Dissemination Rates

Recent advances in commercial satellite direct broadcast technology provide for significantly increased data delivery rates to small, readily mobile receive terminals. This technology makes feasible the transmission of high resolution imagery, video, and large data files in tactically useful time intervals to multiple users. Examples of information which may best exploit direct broadcasting technology include: imagery, intelligence information, missile warning information, meteorological and oceanographic data, mapping and geodesy data, training, and morale, welfare and recreation (MWR) information.

A series of demonstrations have proven the usefulness of employing this technology to the Information Warfare problem. Joint Warrior Information Demonstration (JWID) 1995 was especially useful in establishing the direct broadcast proof of concept by transmitting live video during a recent Tomahawk firing.

The GBS program is being implemented via a three phase evolutionary approach taking maximum advantage of commercial products and technology. Phase I establishes a testbed capability using commercial frequencies, a single channel leased commercial satellite capability in Bosnia and a limited number of CONUS based commercial receivers. Phase II establishes a near world-wide dedicated DoD GBS capability. Phase III will provide for a more robust GBS capability integrated into the overall MILSATCOM architecture being developed by the DoD System Architect. While each phase provides for an evolutionary expansion of GBS capability, the system in any given phase will consist of three basic segments: a Broadcast Management segment which interfaces with data providers, and manages and transmits the broadcast data; a Space segment which provides the satellite relay and coverage capability; and the Terminal segment which receives broadcast data and interfaces with the user. This paper focuses on the development of the Phase II Space Segment and its relationship to the overall Phase II GBS system.

As the need for GBS coalesced, components within both DoD and industry recognized a unique opportunity for providing a significant capability within a short time frame at minimum investment. A GBS payload could be hosted on the last three UHF Follow-on (UFO) satellites for the minimal cost of the GBS payload development and integration. Satellite development costs and launch costs, always a major factor in a space program, had already been incurred by DoD. In establishing the GBS program, the Deputy Secretary of Defense directed the Phase II Space Segment be hosted on UFO satellites F8, F9 and F10. In March 1996, the Navy Program Executive Officer for Space, Communications and Sensors (PEO-SCS) through the UFO Program Office awarded a contract modification to Hughes Space and Communications (HSC) to integrate a GBS capability into UFO. The GBS payload would be in addition to the existing UHF and EHF payloads being deployed to support DoD operations.

GBS ARCHITECTURE

The overall architecture of the GBS is shown in Figure 1. Information products from a variety of sources, both national and theater-based, will be sent to a Broadcast Management Center (BMC).

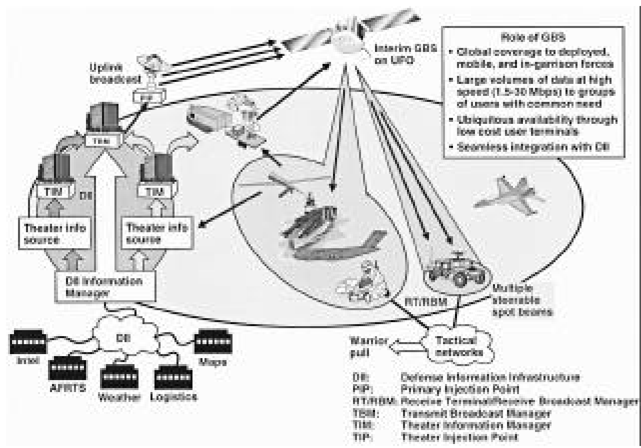

Figure 1. Phase II Global Broadcast Service Architecture

The BMC gathers the data and schedules its insertion into the broadcast stream based upon the direction and priorities received from the supported CINC's and their functional users. The system allows the CINC to tailor the broadcast in response to the operational environment and needs of the users.

The broadcast stream is transmitted to the satellite via an uplink facility either in-theater or at a fixed facility. The fixed facility, or Primary Injection Point (PIP), injects both national and theater generated information. Each Phase II GBS Payload is served by a PIP located within the footprint of the payload's fixed receive antenna. The in-theater uplink, or Theater Injection Point (TIP), provides the ability to inject information products directly from the theater. The TIP is served by the GBS steerable receive antenna. The steerable antenna allows the TIP to be located anywhere within the satellite field-of-view.

The information products are transmitted via the UFO satellite to forces over a large geographic area. The three independently steerable spot beams comprise two 500 nautical mile (Nmi) spots (when measured at the sub-satellite point) and one 2000 Nmi spot. The high power transmitters on the Phase II GBS Payload allow users to receive the broadcast streams at data rates up to 30 Mbps with a small 22-inch diameter, low cost terminal.

The deployment of GBS payloads on UFO will be the first dedicated military deployment of GBS concepts on a nearly global basis. As Figure 2 demonstrates, the Phase II GBS Payload on F8 through F10 provides near world-wide coverage to latitudes between 70 degrees south and 70 degrees north. Phase II GBS will significantly enhance existing MILSATCOM services and provide a testbed for refining future Objective GBS requirements and operational concepts.

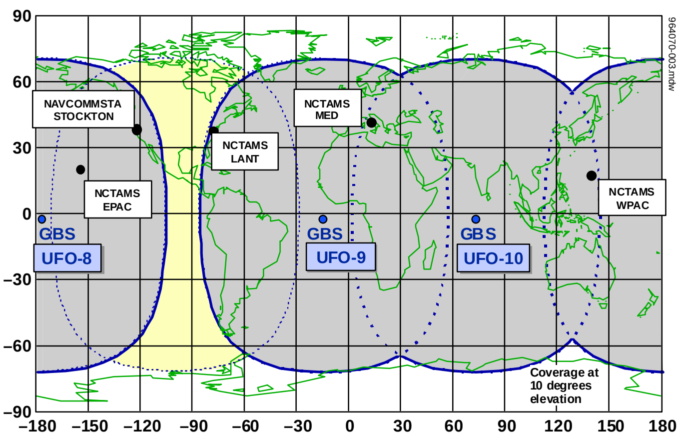

Figure 2. UFO GBS Communications Coverage

PHASE II GBS PAYLOAD CAPABILITIES

The Phase II GBS payload provides high speed digital communications at data rates up to 30 megabits per second (Mbps) per transponder. It is designed to be a flexible tool for the development of the global broadcast service with respect to allocation of transponder resources between coverage areas and also transparency to ground implementations and waveforms.

Figure 3 summarizes the GBS mission and capabilities. Using the military Ka frequency band, each spacecraft has 4 wideband transponders, two receive spot beam antennas (one of which is steerable), and 3 independently steerable transmit spot beam antennas.

A ground commandable switch matrix on the payload provides full connectivity between the receive antennas and the four transponders, allowing the inputs to a receive antenna to be routed to any or all of the transponders. Two transponders are routed to each of the narrow spot beams, with one of those transponders having the capability to be switched between the narrow spot and wide area spot. By taking advantage of the steering capability of each downlink antenna, the payload can provide an effective coverage area much larger than the individual 500 or 2000 Nmi areas. Each steerable spot

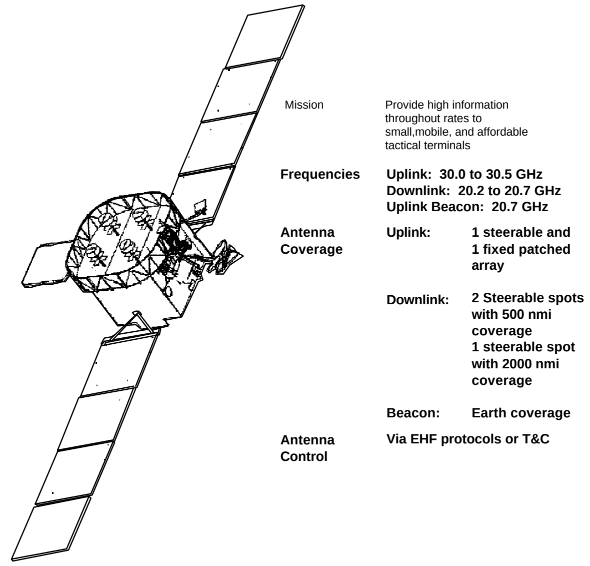

Figure 3. Phase II GBS Mission and Capabilities

beam can be commanded anywhere within the 10° elevation contour using either the telemetry and command (T&C) link or UFO EHF Subsystem Low Data Rata (LDR) C2/C3 protocol messages.

In addition to the GBS communications payload, an earth coverage Continuous Wave (CW) beacon is provided for uplink level control and uplink transmit terminal automated tracking.

The Phase II GBS Payload performance parameters are summarized in Table 2. Since the GBS Payload is a frequency translation repeater with no on-board signal processing, it is flexible with regards to data rate. The 33 MHz wide transponders can support data rates from 1.544 to 30 Mbps per transponder.

Parameter	Measurand
Transponders	4
Transponder 3 dB Bandwidth	33 MHz
G/T	Fixed Receive: $\geq$ -2.25 dB/K (edge) Steerable Receive: $\geq$ 1.75 dB/K (peak)
EIRP	Narrow Spots: $\geq$ 53.2 dBW (edge) Wide Spot: $\geq$ 40.7 dBW (edge) Beacon: $\geq$18.5 dBW (edge)
Downlink Coverage Area	Narrow Spots: 500 Nmi @ sub-satellite Wide Spot: 2000 Nmi @ sub-satellite Beacon: Earth Coverage

Table 2. Phase II GBS Payload Key Parameters

PHASE II GBS PAYLOAD DESCRIPTION

The design of the Phase II GBS Payload repeater is based upon Hughes' extensive experience in direct broadcast satellites in the Ku frequency band. Figure 4 displays a simplified block diagram of the GBS payload.

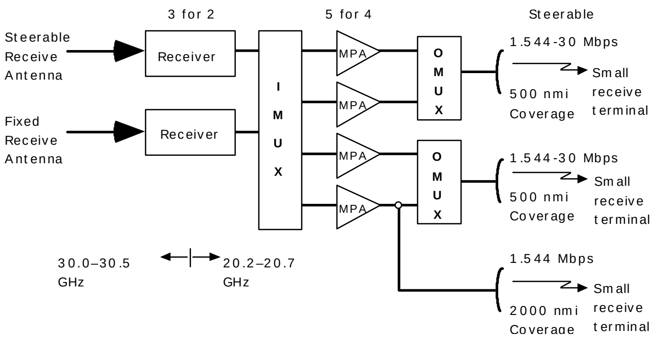

Figure 4. Phase II GBS Payload Block Diagram

Two receive antennas (one fixed, one steerable) allow wideband data to be transmitted from either a fixed uplink site or mobile uplink sites. The receive antennas employ slotted array technology to maximize performance consistent with the launch vehicle fairing constraints. The Ka-band receiver amplifies and frequency translates the entire uplink frequency band. The Input Multiplexer (IMUX) is a resonant cavity bandpass filter assembly which provides channelization. The Transponder Control Unit (TCU) provides automated gain control, which eliminates variations in received signal strength because of weather effects, ground transmitted EIRP changes, etc., in order to keep the Microwave Power Amplifier (MPA) driven to saturation. The MPA consists of two traveling wave tubes power combined and using a common Electronic Power Conditioner (EPC). The Output Multiplexer (OMux) combines the channels for transmission via the transmit spot beam antennas. Channels 1 and 2 are assigned to Spot 1, Channel 3 to Spot 2, and Channel 4 is ground commandable to either Spot 2 or 3, though not simultaneously. The transmit antenna feed components are based largely on EHF derived experience, the reflectors on commercial Ku-band experience, and the steerable mechanisms on other Government programs.

DESIGN AND HARDWARE HERITAGE - COMMERCIALLY DERIVED ELEMENTS

One of the enabling strategies implemented for the Phase II GBS Payload Program is the incorporation of proven commercial hardware and designs in all aspects of the payload architecture. This strategy reduces overall development risk in the program and enabled Hughes to accept the very aggressive schedules on this program. In general, scaling of designs from Ku-band frequencies to military Ka-band was required, but much of the circuit design architecture was incorporated with only minor modifications.

The three major elements in the GBS Payload are the Ka-band Receiver, the Transponder Control Unit, and the Microwave Power Amplifier. The design of much of this hardware is derived directly from that of a high power commercial communications satellite currently under construction which will provide video broadcast and high data rate links. The scaling from Ku-band (12 GHz) to military Ka-band frequencies (20 GHz) was straightforward.

The 65 Watt Traveling Wave Tube (TWT) used in the MPA, while not a commercial product, is based on the TWT for the Milstar Medium Data Rate (MDR) payload. While the TWT's are military in origin, the dual EPC which powers them is derived from a commercial product.

SPACECRAFT MODIFICATIONS

The EHF Payload was incorporated into the UHF F/O spacecraft beginning with F4, providing secure, anti-jam command and fleet broadcast communications. Prior to F4, these functions were accomplished via the SHF Payload. For F8, F9 and F10, the SHF payload will be removed resulting in weight, power, and shelf layout savings, which will allow accommodation of the GBS Payload.

Modifications to the existing spacecraft are shown in Figure 5. These changes demonstrate the flexibility for payload evolution of the Hughes HS 601 three axis, body stabilized satellite. Upgrades to the power subsystem to meet the demands of the GBS Payload are accomplished using designs and technologies available from the Hughes commercial product line. These upgrades include adding a fourth solar panel with Silicon solar cells to each of the existing three-panel solar wings, and upgrading to a higher capacity 164 Amp-Hr battery. Both of these advancements will have flight history prior to the F8 launch.

Using the experience and hardware developed on the EHF Payload, modifications are being made to the Spacecraft Control Processor (SCP) and Baseband Unit (BBU) flight software to provide antenna move and pointing control of the GBS antennas. Thermal control modifications to accommodate the increased spacecraft dissipations

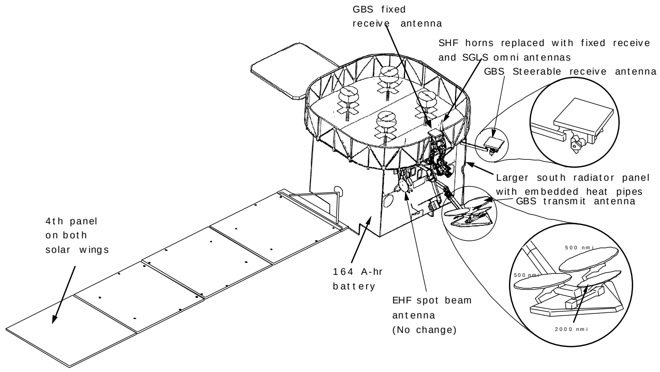

Figure 5. Spacecraft Modifications for Phase II GBS

include a larger South radiator panel with embedded heat pipes. Use of heat pipes is common on many commercial satellites in the HS 601 product line.

INTEGRATED PRODUCT TEAMS ON GBS

We have touched briefly on the utilization of commercial designs and hardware on GBS. A second aspect of Government Acquisition Reform which has been crucial to the success of the GBS Payload development effort is the implementation of Integrated Product Teams (IPT's). The Phase II GBS Payload effort is a very challenging program, having an aggressive schedule requiring launch in less than 24 months. Clearly first pass success is required. An effective teaming relationship between the Navy and Hughes has been the best way to assure that the contract and performance requirements of the product are met on schedule and in the most cost-effective manner possible. The IPT's implemented on the GBS Payload effort build on the very successful Navy-Hughes Team which has successfully launched the seven UHF F/O spacecraft to date.

To facilitate an even more effective management/teaming relationship, a number of IPT's were set up: Engineering/ Production IPT's, Contracts IPT, Risk Mitigation IPT, and a Level-1 IPT comprising leads and principal members from other IPT's. While each of these IPT's has contributed enormously to the success of Phase II GBS Payload, the contributions of the Risk Mitigation IPT are particularly significant.

The charter of the Risk Mitigation IPT is to formulate a Risk Mitigation Strategy, to periodically update the plan to address current issues, and to provide feedback to Engineering IPT's of new issues which need to be addressed. The Risk Mitigation Plan was initially formulated at a joint Hughes-Navy meeting held in March '96. Both the Navy and Hughes brought independently developed risk listings. These listings were consolidated, additional risks identified in these discussions were added, and preliminary mitigation strategies were formulated. Responsible Engineering Authorities (REA's) developed a more detailed mitigation strategy for each risk including criteria for reducing the level of risk, criteria for closure, and estimated completion dates.

This Risk Mitigation program spans all disciplines from Program Management and Contracts to Engineering and Product Assurance issues. It has two principal benefits: it focuses efforts on those risks with the highest leverage and it provides a framework for continually re-evaluating risks and generating new mitigation strategies as required.

STATUS OF THE PHASE II GBS PAYLOAD

The GBS Payload single string engineering model (EM) test was successfully completed in November 1996. This test validated the repeater performance and proved out the new GBS Special Test Equipment (STE) and RF test software.

All elements of the GBS Payload were included in this end-to-end test: 30 and 20 GHz waveguide switches, transmit reject filter, Ka-band receiver, spur reject filter, IMUX, transponder control unit, microwave power amplifier, OMux, receive reject filter, variable attenuators, and associated waveguide.

The GBS Payload program has now transitioned from the non-recurring phase to production. Flight units for F8 have completed assembly and test and have been integrated on the F8 spacecraft. The F8 spacecraft has completed final integration, and the GBS antennas have been integrated. The spacecraft is now undergoing its integrated system test program prior to environmental testing which is planned for November '97. F8 will undergo a final system level test series, and will ship to Cape Canaveral in January '98. F8 is on schedule to launch in February '98.

The F9 spacecraft is nearing completion of its integration phase. It will begin system level testing in October '97 and is on schedule to launch in August '98. The Phase II GBS system will be fully operational when F10 is placed in service in early 1999.